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Quantitative analysis of climate change impact on Zhangye City's economy based on the perspective of surface runoff

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ABSTRACT

Zhangye City is a representative agricultural city in China where agriculture depends heavily on precipitation in the Heihe River Basin; water use for agriculture plays a key role in the sustainable development of total water resources. This study, based on the predicted surface runoff by GCM, uses a CGE model with a water-land resources account, to analyze the impact of climate change on Zhangye City's economy and agricultural water consumption. The results show that climate change increases surface runoff by 8.84%. The increasing surface runoff contributes most to the total water consumption, increasing by 8.11% accompanied by a small GDP expansion of 0.12%. Relative to the industrial structure, agricultural sectors benefit most. Contrarily, export-oriented industrial sectors see a decrease in benefit, resulting in employment migrating to lower value-added agricultural sectors. From the water types, the consumption for underground and other water also rise by 6.69% and 5.73% respectively, due to the economic scale expansion effect of the agricultural sectors. For varieties of crops, grain crops consume more water because of its greater water intensity. And the land is mostly transferred from economic crops to grain crops. Therefore, the government should pay attention to changes in the consumption propensity of water resources, continue to promote agricultural water-saving measures and the adjustment of agricultural planting structure.

1. Introduction

Water is an important natural resource (Griffin, 2016; Karamage et al., 2016; Dalin et al., 2015) and its supply is directly related to socioeconomic development globally (Gleick, 2014). Due to the impact of climate change on the world water system, there has been increasing reallocation of global water resources (Chen et al., 2014). Some regions (e.g., semi-arid) and some sectors (e.g., agriculture (UNWWDR, 2003) are very sensitive to changes in water supply. Northwest China is a representative arid and semi-arid area with relatively limited water supply (Chen et al., 2012). Zhangye City (see Fig. 1), is located in northwest China in the Heihe River Basin. According to its development statistics, Zhangye City's gross domestic product (GDP) was 40 billion yuan with a per capita GDP of 32,729 yuan, and its population was 1.2 million in 2016 (Statistics of Zhangye, 2016). The development of Zhangye City's agriculture relies on precipitation, which directly affects the output of both economic and food crops. The impact of the water supply on agricultural needs further study. Water related problems have been studied mainly in terms of water price, water tax, and water efficiency, etc. Water pricing (Moore et al., 1994; Doppler et al., 2002; Bartolini et al., 2007; Giannakis et al., 2016) plays a key role in coordinating water use. Zhong et al. (2015) incorporated the water parallel pricing system (irrigation water and pipe water) of China within a CGE (Computable General Equilibrium) model to estimate the effects on agricultural production. Water tax (Höglund, 1999; Qin et al., 2012; Zhao et al., 2012) affects the cost of water use and thus water demand. Maria et al. (2006) set six scenarios of water tax to assess the effects on water use, production, consumption, and international trade patterns

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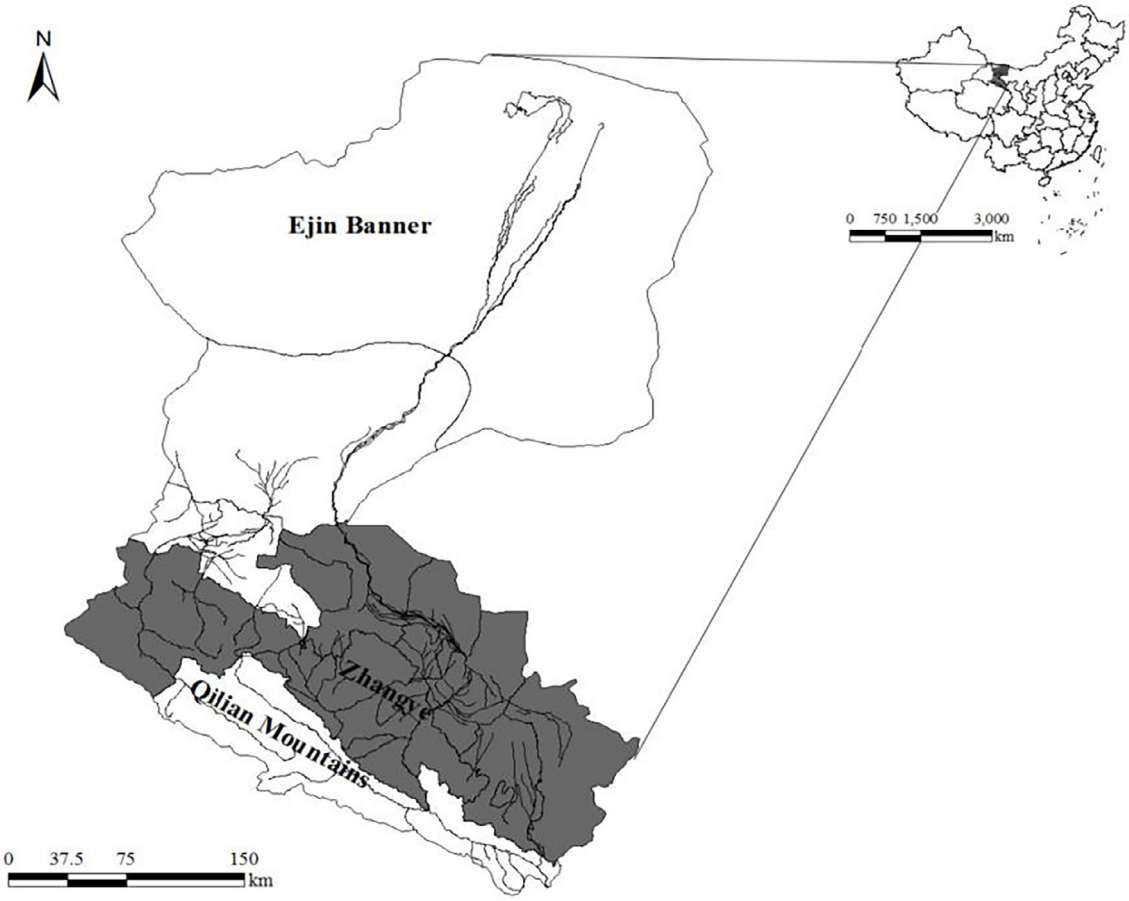

Fig. 1. The location of the study area.

with Global Trade Analysis Project (GTAP) model. In addition, other improvements in agricultural water use efficiency (Cooper et al., 1987; Zhang et al., 1999; Wallace, 2000; Bouman and Tuong, 2001; Howell, 2001; Davies et al., 2002; Condon et al., 2004; Chaves and Oliveira, 2004; Blum, 2005; Chapagain et al., 2006; Geerts and Raes, 2009) have been undertaken. Liu et al. (2017) applied a static CGE model with a composited water-land resources account to assess the impact of improving agricultural water use efficiency on economy, water conservation and land allocation based on Zhangye City's data.

Water supply issues are attracting increasing interest. Numerous researchers using the results of General Circulation Model (GCMs) studied the impact of climate change on water supply, especially for arid and semiarid regions because of its water scarcity and sensitivity to climate change (Wittwer, 2006; Deng et al., 2008; Liu et al., 2012; Seung et al., 1997, 1999). Besides, some studies focused on the water supply for irrigation for agricultural production's dependence on water and the importance of food security (Seung et al., 1999; Berrittella et al., 2007; Diao et al., 2007; Calzadilla et al., 2008). But few attempts contributed to the change of water supply's further economic impact on the regions (Horridge, 2000). Some researchers analyzed the effect of total water supply reduction on the local economy but without delineating sectors, especially agricultural sectors. Wittwer (2006) considered a scenario of 25% water shortage to assess its economic effect by using a multi-regional CGE model. Deng et al. (2008) analyzed the economic effect by shocking Beijing's water supply with an increase or reduction of 10%. Liu et al. (2012) set various water supply scenarios to evaluate the total effect on Tianjin's economy with CGE model. Some studies also assessed the effect of water supply reduction with a focus on agriculture. Seung et al. (1997, 1999) analyzed the economic impacts of transferring surface water from agricultural to recreational use (reallocating 30,000 acre-feet of water) at the Stillwater National Wildlife Refuge in Churchill County with a comparison between supply-determined SAM and CGE models, distinguishing three agricultural sectors and five non-agricultural sectors. Berrittella et al. (2007) considered the economic impact of restricted water supply by setting five scenarios and disaggregating agricultural production into five different sectors, assuming that water is mobile between them, but segregated between agricultural and water distribution service sectors. This study finds that without water supply constraints, some regions will enjoy a competitive advantage in agriculture. Diao et al. (2007) evaluated direct and indirect effects of groundwater on agricultural and non-agricultural sectors to extend the scope for water policy. Calzadilla et al. (2008) investigated the role of green (rain) and blue (irrigation) water resources in agriculture, running water crisis scenario and sustainable water use scenario to assess the effect based on GTAP-W model, but this study did not offer a detailed quantifiable loading in respect of water supply.

Compared with existing researches about the impact of climate change on water supply of Zhangye City, this study makes the following contributions. (1) Researches studying the effects of climate change on water supply, generally focused on the water scarcity or the impact on agricultural production, and few of them further analyzed its macro-economic impact. In addition, researches analyzing the impact of water supply changes on the macro economy using CGE model, often used subjective assumptions, such as 10% or 20% changes in water supply. Until recently, few studies combined climate, hydrologic and economic models to examine the impact of climate change on water supply and its economic impact, especially for Zhangye City. In order to offer more useful suggestions to water management and industrial restructuring of Zhangye City, our study analyzes the impact of the changes of water supply caused by climate change on economy by coupling GCMs, the Soil & Water Assessment Tool (SWAT), and CGE model. (2) Few

previous studies on Zhangye City have examined the water types. But climate change has a more significant impact on surface water, and the limited supply of surface water and other water types have different impacts on economy and sectors. So, it's important to distinguish water types for Zhangye City's actual impact analysis. In this paper, surface water, underground water and other water are distinguished in our CGE model. (3) Most studies only took agricultural sector as a whole, or segmented it in simple ways, i.e., two or three agricultural sectors. But for Zhangye City, Agricultural sector is the biggest user of surface water, and significantly affected by changes of water supply. Above all, different crops consume different amount of water resources and their economic impacts are also not same. Hence, dividing agricultural sector into different crops is essential for the economic impact assessment. According to the feature and reality of Zhangye City, agricultural sector has been subdivided into seven sectors (wheat, corn, oilseed, cotton, fruit, vegetables, and other agriculture) in our CGE model.

In summary, we used GCMs to model future climate change through calculating the 30-year average annual precipitation and temperature in Zhangye City. Then we simulated the water yield change using the SWAT model to get the cumulated runoff from year 2001 to 2030 and finally to get the quantity change of surface water supply which was further introduced into the CGE model to analyze the economic impact of surface water supply increase on social economic and agricultural sectors in Zhangye City, a core city in Gansu province. The remainder of the paper was organized in five sections. First, after this introduction, an overview of the climate model (GCMs, SWAT), and economic model (CGE model) to be used in the simulations were presented, focusing on their general features and coupling mechanism of models. Meanwhile, the scenario of surface water supply increase between year 2001–2015 and 2016–2030 was designed as a prediction index to be introduced into CGE model to analyze the economic effect. Second, the simulation results of CGE model about macroeconomic impact, sectors' output and allocation of water and agricultural land resources across sectors were discussed. Third, we provided a discussion in an attempt to evaluate our findings and put them into perspective, considering their extension and limitations. After that was the conclusion and policy recommendations.

2. Materials and method

The models we use in this study are GCM, SWAT (climate model) and CGE model (economical model). According to the measurement of GCM and SWAT, we can obtain the accumulated runoff from year 2001 to 2030 caused by climate change. Further, comparing the median cumulative runoff of the first fifteen years (2001–2015) and that of the later fifteen years (2016–2030), we introduce the increased runoff index into the CGE model to assess the impact of an increase in surface water supply caused by climate change on agricultural water consumption. In the following three sub-sections, the detailed description of the structure of GCM and CGE model are introduced. In Section 2.1, the description of GCM is provided, which includes how the accumulated surface runoff of year 2001 to 2030 is obtained. In Section 2.2, we introduce the production and demand modules of the CGE model; this includes how to find optimal output with constraint of cost and how private consumption and government consumption proceed. In Section 2.3, we introduce the scenario design according to GCM and CGE model.

2.1. The measurement of GCMs

The GCMs are arguably the best available tools for modeling future climate. Yet GCMs provide information at a resolution that is too coarse to be directly used in hydrological modeling. First, the average annual precipitation and temperature of 30 years (1980–2010) are calculated and adopted as a baseline for selecting the GCMs. We consider future climate change scenarios for the basin by using the spatially distributed outputs from 10 GCMs under RCP 4.5 scenario. The climate projections of the Max Planck Institute (MPI) are downscaled to the 3 km × 3 km grid of the study area, bias is corrected and climate change scenarios are developed by MPI for Meteorology. The annual mean values of 10 GCM spatial data from 2006 to 2030 are calculated according to the basin perimeter, and one out of ten GCMs is also selected based on the historical trends and annual averages of temperature and precipitation. The MPI model is finally chosen through comparison. We consider the impact of changed land use on regional climate and the land cover data before Weather Research and Forecasting (WRF) simulation are dynamically replaced with land use change data based on the simulation with the DLS model. Finally, the data simulated by the regional climate model is matched with meteorological sites, and the meteorological site data is prepared for the simulation with SWAT.

The study area is first divided into sub-watersheds, which are subdivided into hydrological response units. Besides, for each sub-watershed, the climate data used are taken from the GCM grid point that is the closest to its centroid. To improve performance, the SWAT model is calibrated and validated by adjusting several parameters and comparing the simulated stream flow with observed values. The most sensitive parameters are identified with the built-in sensitivity analysis tool in SWAT. The daily stream flow observation data from Yingluoxia Hydrological Station in 2004 are used for calibration, and the observation data in 2005 are used for validation. Therefore, we simulate the water yield change using the SWAT model during 2015–2030 to get the cumulated runoff from year 2001 to 2030.

2.2. The CGE model

Based on the temperature and precipitation changes obtained by GCM and surface runoff further stimulated by SWAT model, the CGE model is used to simulate and analyze the economic impact of surface water increase in Zhangye City. This paper uses the CGE model developed jointly by Chinese Academy of Science Institutes of Science and Development (CASISD), and Victoria University's Centre of Policy Studies. It incorporates economic characteristics and data of Zhangye City. The economic data for the model is derived from the 2012 input–output tables of Zhangye City, the water resource data is taken from the first national census for water organized by the Ministry of Water Resources in 2011, and the land use data is obtained from remote sensing image data produced by the Heihe River project group in 2012.

The CGE model includes 48 sectors, various agricultural sectors including wheat, corn, oilseed, cotton, fruit, vegetables and other agriculture; 4 primary inputs (labor, capital, land, and water, water can be further divided into surface water, underground water and other water) and 6 economic agents (production, investment, households, government, inventory, and other regions). The model also considers 3 types of margin, which are transport warehousing, insurance, and trade. Besides these, we introduce water and land resource accounts as primary factors based on the constant elasticity of substitution (CES) in the model, similarly, the three kinds of water are also a CES alternative, for analysis of the water and land reallocation when facing price adjustment. The CGE model assumes that when the economy reaches a state of general equilibrium, it is a perfectly competitive market, for which the ORANI model would suffice (Horridge, 2000; Dixon et al., 2016; Nassios et al., 2016; Giesecke and Tran, 2017).

In this paper, the short-term closure is used to analyze the impact on the economy of Zhangye City of improved agricultural water use efficiency. The specific short-term closure assumptions are as follows. In the labor market, real wages are fixed and employment endogenous. In the capital market, capital stocks are fixed and the rate of return on capital endogenous. Government spending and the tax rate are exogenous. Labor growth, technological progress, and capital accumulation jointly drive economic growth. The total amount of land supply is constant and sectors with increasing land returns attract more land. Besides, agricultural land and non-agricultural land are not transferrable. To be more specific, agricultural land can semi-automatically

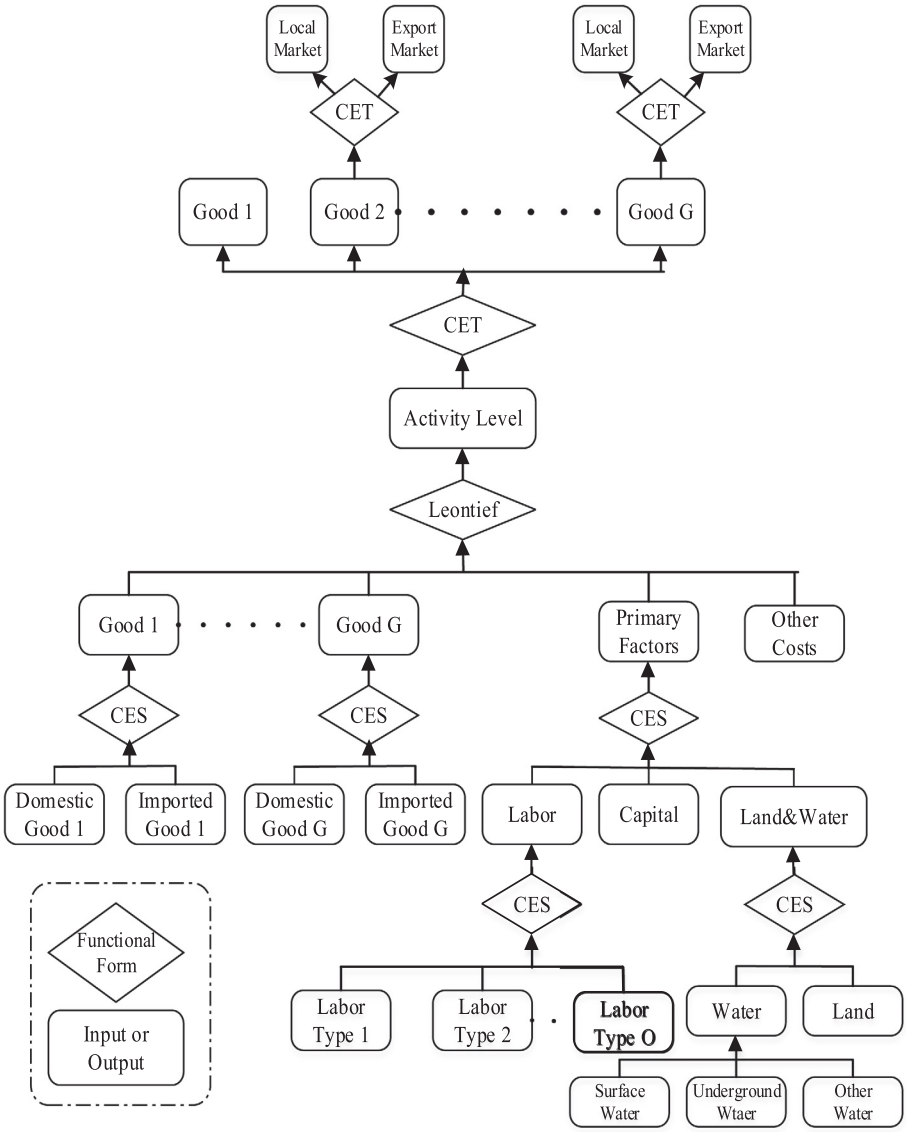

Fig. 2. The production structure of the CGE model with land and water account in this study.

transfer within the agricultural sector, while non-agricultural land cannot transfer within non-agricultural sectors.

2.2.1. Production module

The production module describes input decisions and output distribution in production sector (see Fig. 2). According to the principle of cost minimization, the manufacturer determines the optimal input. And outputs are assigned to the local market and to export according to the principle of profit maximization.

In the model, a multi-layer nested structure is used to describe the input decisions. The top layer contains the intermediate inputs, the primary factors inputs, and other costs based on the Leontief production relationship. In terms of output, the Constant Elasticity of Transformation (CET) function is used to determine the supply of the product in the local market and the output of export.

An improvement of our model is to introduce the land accounts and land-water nesting in the designed model in this study. As shown in Fig. 2, from the bottom layer, surface water, underground water, and other water resources form a CES nest of water resources. Water resources and land then form a middle layer, CES bundle of water-land.

2.2.2. Demand module

The final demand for commodities includes household consumption, government consumption, export, investment, margins, and inventory. Of these, the household demands follow the Linear Expenditure System (LES). Government consumption and inventory are set to be exogenous. The investment demand procedure is similar to the input-sourcing decisions in production. The optimum is achieved by cost minimization. Margins demand depends on the basic demand of commodities and the coefficient of margins technical change. Export depends on the relative price of the product j in domestic market and foreign market, the demand quantity in foreign market and the demand elasticity. There are two kinds of export products, namely, traded and non-traded goods. The demand curve for traded goods is downward-sloping with fixed demand elasticity of price.

In general, having introduced the framework of GCM model and CGE model, Fig. 3 shows the coupling mechanism of the two models in this study. GCM and SWAT are climate models, and CGE is an economical model. First, a climate change RCP 4.5 scenario is selected to a GCM model MPI, obtaining the annual averages of temperature and precipitation from 2006 to 2030 calculated according to the basin perimeter and historical trends. Then the variation of surface runoff is calculated by SWAT model based on the changes of temperature and

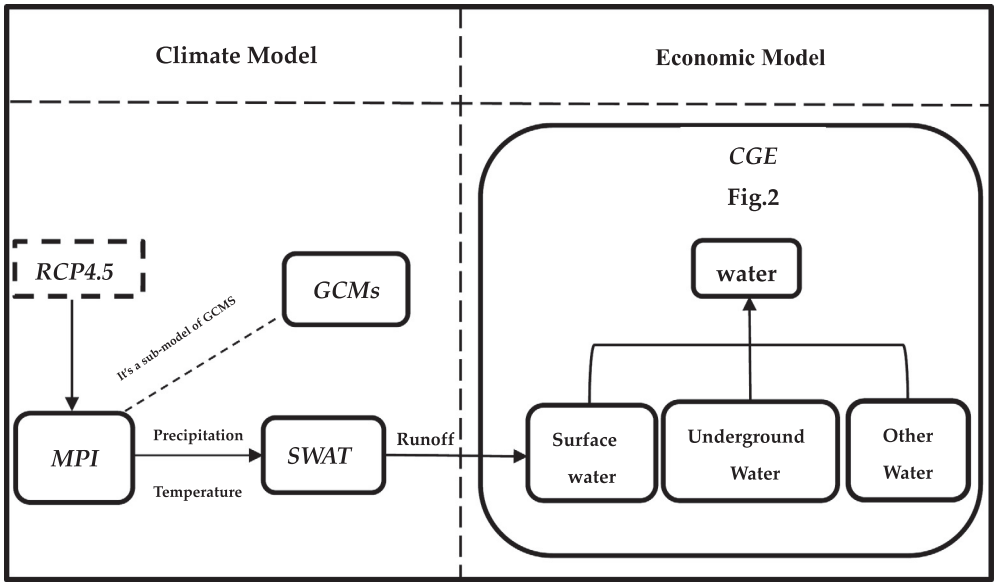

Fig. 3. The coupling mechanism of models that are used in this study.

precipitation from 2006 to 2030. Finally, according to the agricultural water characteristics in Zhangye City, the agriculture sector is decomposed into wheat, corn, oilseed, cotton, fruit, vegetables, and other agriculture. Further, the water is divided into surface water, underground water and other water for the research convenience of follow-up economic impact assessment of agricultural surface runoff increase caused by climate change. The GCM and SWAT model link climate variables with land, precipitation, temperature and runoff. And the CGE model links land, water, intermediate inputs, and other primary factors with production, trade, and consumption of 48 commodities. This study has achieved the mechanism coupling of the climate model and economic model, providing a meaningful perspective for the economic impact of surface water rise caused by climate change in Zhangye City.

2.3. Scenario design

Based on the above description, we obtained the cumulated runoff from year 2001 to 2030 by GCM (see Fig. 4). Since 2001, the surface runoff in Zhangye City has shown a trend of varying degrees of growth. In 2001, the surface runoff in Zhangye City was 43.61 m^3/s. After varying degrees of growth, by 2015, surface runoff was 81.34 m^3/s. The mean value of cumulated runoff between year 2001 and 2015 is calculated to be 64.25 m^3/s. In 2016, the surface runoff was 40.45 m^3/s. According to the GCM, surface runoff in Zhangye City in 2030 is 86.43 m^3/s, and the mean value of cumulated runoff between year 2016 to 2030 is calculated to be 69.93 m^3/s. Compared to the first fifteen year (2001–2015), the mean value of cumulated runoff of the second fifteen year (2016–2030) will increase by 8.84%. That is to say, climate change will lead to an increase in surface runoff in the future (Wu et al., 2015; Zhang et al., 2016). In order to have a deeper understanding of the impact of increasing surface water supply caused by climate change, we introduce this prediction index into CGE model to analyze the economic effect by loading the surface water supply 8.84%.

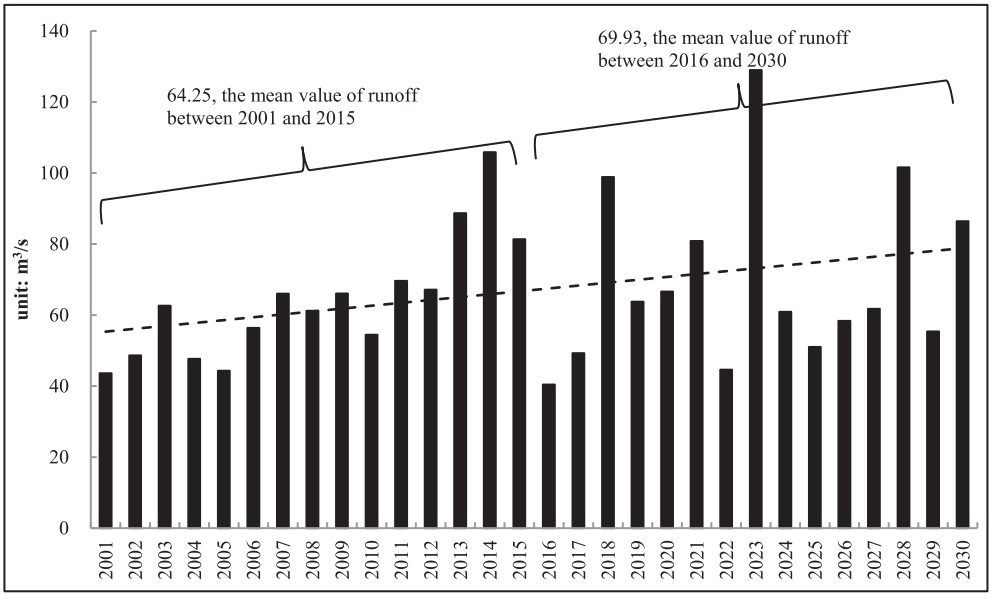

Fig. 4. the cumulated runoff calculated by GCMs from 2001 to 2030.

3. Results of simulation analysis

An increase in surface runoff caused by climate change will directly impact sectors with high surface water intensity. In Zhangye City, only eight sectors consume surface water, wheat, corn, oilseed, cotton, fruit, vegetables, other agriculture, water production and supply sector, which are mostly agricultural products. As the surface water intensity of these sectors differ, their output changes vary in degree. In general, the higher the surface water intensity, the more beneficial it is to the change of each sector's output. Then the output changes of these sectors are channeled to other sectors through upstream-downstream production linkages, causing changes in other sectors. Besides this, the increasing surface runoff will drive the surface water prices down, which will lead to price adjustment in the primary factor market. This eventually results in a primary factor substitution for the sectors. In the following part, the results of macroeconomics, sector-wise transformation, and water-land reallocations are summarized. In Section 3.1, we interpret the change of GDP, CPI, employment, trade balance and total water consumption and explain the underlying reasons. In the Section 3.2, the top 10 benefited and damaged sectors are analyzed. In Section 3.3, we provide the analysis of water and land resources reallocations across sectors.

3.1. Macroeconomic impact

1. An increase in surface runoff caused by climate change will expand Zhangye City's economy in a narrow range, GDP growth being 0.12% (see Table 1). This is mainly caused by two factors. On the one hand, with the surface water accounting for 67% of total water use, as surface water supply increases, the surface water will directly promote economic growth to some extent (0.05%, the contribution of surface water to GDP growth). On the other hand, the increase of employment will also make a contribution to the GDP growth, which is 0.05%. Further, the expanding economy should then lead to higher household consumption (0.08%) and a rising capital price leads to an increase in return on investment, which will increase the investment by 0.17% (see Table 1).
2. The consumer price index (CPI) rises by 0.02% (see Table 1). Even though the increase of surface runoff has led to lower prices for certain consumer goods with higher surface water intensity (e.g. wheat, corn, fruit and vegetables), higher capital prices will cause the price in capital-intensive sectors (e.g. real estate sector with small elasticity of supply curve) to rise, which account for a large proportion of consumer goods. This eventually results in a small increase in the CPI.
3. An increase in surface runoff will stimulate export by 0.10% and import by 0.09% (see Table 1). Surface water is mainly used for agricultural and water supply sectors. Because of the increase in surface runoff, the prices of export-oriented agricultural products (e.g. wheat, corn, cotton, fruit and vegetables) fall. This comparative price advantage will spur a small expansion in export. The increase in import is mainly due to the rising costs of export-oriented sectors as a result of rising prices, such as the construction sector and chemical sector.
4. The employment in the labor market will increase by 0.11%, and a nominal wage rise by 0.02% (see Table 1). In the short term, fixed real wage and increase in surface runoff, will keep the marginal output of labor unchanged, and the increase in fixed factors will give rise to higher employment. This ultimately leads to an increase in demand for labor. Moreover, the increase in labor demand will lead to upward pressure on the nominal wage, driving up the nominal wage.
5. An increase in surface runoff will increase the total water consumption by 8.11%, at the same time, the surface water, the underground water and other water will also rise by 8.84%, 6.69% and 5.73%, respectively. It should be noted that the reasons for their changes are quite different. For surface water, the increasing surface runoff causes surface water price to fall, creating a rise in surface water consumption. For underground water and other water, although the decline in surface water prices can make prices of other water and underground water relatively expensive, economic scale expansion has led to an increase in demand for them. Because of the increase in surface runoff, which will lead to a cost advantage for the agricultural sector and the water production and supply sectors, the output of these sectors will expand, bringing about an increase in demand for underground water and other water. The increase in demand for the three kinds of water sources will eventually lead to an increase in total water consumption.

Table 1
The macro impact of an increase in surface runoff caused by climate change on Zhangye City's economy compared with baseline[1].

Macro variables	Change (%)
GDP	0.12
CPI	0.02
Household consumption	0.08
Investment	0.17
Export	0.11
Import	0.09
Employment	0.11
Nominal wage	0.02
Capital price	0.15
Land price	0.98
Quantity of total water consumption	8.11
Quantity of surface water	8.84
Quantity of underground water	6.69
Quantity of other water	5.73

Data resource: CGE simulation.

[1] Baseline means the basic scenario that surface runoff did not change.

3.2. Sectorial impact

An increase in surface runoff caused by climate change in Zhangye City will bring about varying degrees of output expansion or contraction in different sectors. Among all the 48 sectors, outputs of 20 sectors decreased, with water, environment and public facilities management sectors suffering the most (0.048%). Outputs of 28 sectors increase, with corn benefiting the most (1.74%). In general, the benefit to the sectors' output impact is greater than the damage. To simplify the analysis, this section focuses only on the top ten sectors of the increase or decrease in output. Most of damaging sectors are export-oriented sectors, mainly due to the greater contributing proportion of export to total output. Benefiting sectors are found mostly in the agriculture sectors and water production and supply sectors, mainly because of the price advantage due to the surface water increase. Other sectors are affected by the impact of the upstream and downstream linkages or primary factor market, leading to changes in output.

3.2.1. Benefited sectors

Table 2 lists the top 10 benefited sectors from an increase in surface runoff caused by climate change in Zhangye City. Most of these sectors are agriculture sectors with high surface water intensity. The basic database shows that only agriculture sectors and water production and supply sector consume surface water. Thus, the output of corn (1.74%), fruit (1.28%), cotton (1.27%), wheat (0.92%), water production and supply (0.82%) and vegetables (0.47%) benefit most (see Table 2). The different changes in output of these six sectors are mainly due to the surface water increase. It should be noted that output changes are not strictly based on the value of surface water intensity. Sometimes, the initial value of surface water input and output is also critical. For example, the surface water intensity of corn is slightly lower than that of cotton, but the output of corn increase is more than that of cotton. This

Table 2
The top10 benefited sectors from an increase in surface runoff caused by climate change in Zhangye City compared with baseline.

Benefited sectors	Change (%)		Fan decomposition
	Output	Price	
Corn	1.74	-0.47	Export (1.74)
Fruit	1.28	-0.35	Export (1.27)
Cotton	1.27	-0.34	Export (1.25)
Wheat	0.92	-0.25	Export (0.91)
Water production and supply	0.82	-0.33	Dom share (0.74)
Vegetables	0.47	-0.13	Export (0.47)
Wholesale and retail	0.10	0.07	Local market (0.10)
Residential service	0.08	0.04	Local market (0.09)
Finance	0.08	0.08	Local market (0.09)
Electric power	0.08	0.00	Local market (0.08)

Note: The table only lists the main factor leading to output change. Fan decomposition divides the sector output change into three parts: Local Market, Domestic Share and Export. Local Market represents output change due to changes in Local demand. Domestic Share indicates that the change in output is caused by the change in the local market share compared with the price of the imported goods. Export shows output change caused by changes of export demand. The figures between brackets in the last column means the output change results from the main factor of Fan decomposition.

is mainly because the water input and output value of corn is much greater than that of cotton. Other sectors such as residential service sector, electric power sector, wholesale and retail sector and finance sector are mainly affected by the macro economy environment change. The mechanisms of output change of benefiting sectors are as follows.

1. Cost advantage affected by surface water intensity. The basic database shows that the surface water is only used in agricultural sectors (99%, the proportion of surface water use to total surface water) and production and supply sector (1%). And the surface water intensities of these sectors are high. Increasing surface runoff will drive down the surface water prices of wheat, corn, fruit, vegetables, cotton, water production and supply sector. This relative price advantage thus results in output expansion, showing itself as an increase in export demand of wheat, cotton, corn, fruit and vegetables, with intermediate input demand of water production and supply sector. Moreover, the output expansion in the agricultural sector leads to an increase in demand for residential service and electric power, prompting a small increase in the output of those two sectors
2. Margin demand leading to output expansion. In the basic database, most of the output of wholesale and retail sector (99%, proportion of margins to total output) and finance sector (53%) are for margins. The margin of wholesale and retail sector is mainly for export. Therefore, the export expansion of wheat, corn, cotton, fruit and vegetables has directly stimulated the export demand of the wholesale and retail sectors. Besides this, the margin of the finance sector is mainly used for household consumption, and the increase in consumer demand leads to an increase in finance sector output.

3.2.2. Damaged sectors

Table 3 lists the top 10 damaged sectors, which are mainly export-oriented sectors. The variations of output changes are fairly small, with the water, environment and public facilities management sector suffering the most by having a reduction in output of 0.048% (see Table 3). The ten most damaged sectors tend to be those in which export demand falls: some sectors are affected by the labor price, and some sectors are affected through the upstream and downstream production chain. The specific reasons are as follows.

1. Increasing intermediate input costs lead to lower export scale. The database shows that coal mining and washing accounts for 20% of all the intermediate inputs in the food manufacturing and tobacco processing sector, which is export-oriented sector. As 21% of coal mining and washing output flow to the electric power sector, with the output expansion of electric power, the demand for coal increases. This leads the capital price of coal mining and washing to rise and drives the higher price of coal mining and washing. The higher intermediate input costs of food manufacturing and tobacco processing sector has resulted in output contraction, presenting a decline in export scale.
2. Decline in export demand as increased labor costs for labor-intensive sectors. In water, environment and public facilities management sector, public administration sector, research sector and petroleum processing, coking and nuclear fuel processing sector, labor account for 83%, 93%, 57% and 59% of total primary factor inputs, respectively. Because of the rising labor price, the costs of these sectors increase, thus export prices rise and export demand falls.
3. A fall in export or intermediate input demand due to the declining output in downstream sectors. Most output of the oilseed sector (74%, the proportion of oilseed flowing to food manufacturing and tobacco processing sector) and paper making, printing and sport goods manufacturing sector (61%) flow to food manufacturing and tobacco processing sector, the output contraction of which will lead export demand for upstream sectors to reduce. This will further drive the demand for scrap to decline for the 48% of scrap flowing to paper making, printing and sport goods manufacturing sector. In addition, the output of metal product sector and metal mining and dressing sector are mainly used by construction. Similar to the above two points, rising prices of coal mining, washing and labor will reduce the competitiveness of the construction sector, leading to shrinkage in sector output. Hence the reduction in the output of the latter will lead the export demand for products of the former sectors to reduce.

Table 3
The top10 damaged sectors from an increase in surface runoff caused by climate change in Zhangye City compared with baseline.

Damaged sectors	Change (%)		Fan decomposition
	Output	Price	
Water, environment and public facilities management	−0.044	0.011	Export (−0.044)
Paper making, printing and sport goods manufacturing	−0.026	−0.001	Export (−0.031)
Research	−0.017	0.005	Export (−0.012)
Metal mining and dressing	−0.017	−0.028	Export (−0.017)
Public administration	−0.016	0.020	Export (−0.019)
Food manufacturing and tobacco processing	−0.015	0.0005	Export (−0.017)
Petroleum processing, coking and nuclear fuel processing	−0.015	0.001	Export (−0.029)
Metal products	−0.013	−0.005	Export (−0.027)
Scrap	−0.013	−0.003	Local market (−0.015)
Oilseed	−0.012	−0.002	Export (−0.012)

3.3. Allocation of water and agricultural land resources across sectors

Following the second part, sector output changes can cause primary factor market price adjustment, leading to the reallocation of primary factors in the economy. The simulation results show that an increase in surface runoff caused by climate change will make a total water consumption increase of 8.11% (absolute value is 192.15 million m^3) with surface water, underground water, and other water increasing by 8.84% (141.25 million m^3), 6.69% (47.04 million m^3) and 5.73% (3.85 million m^3), respectively, mainly through agricultural and water production and supply sector (see Fig. 5(a)). Besides, the increase of water consumption used by grain crops (e.g. wheat and corn) is greater than

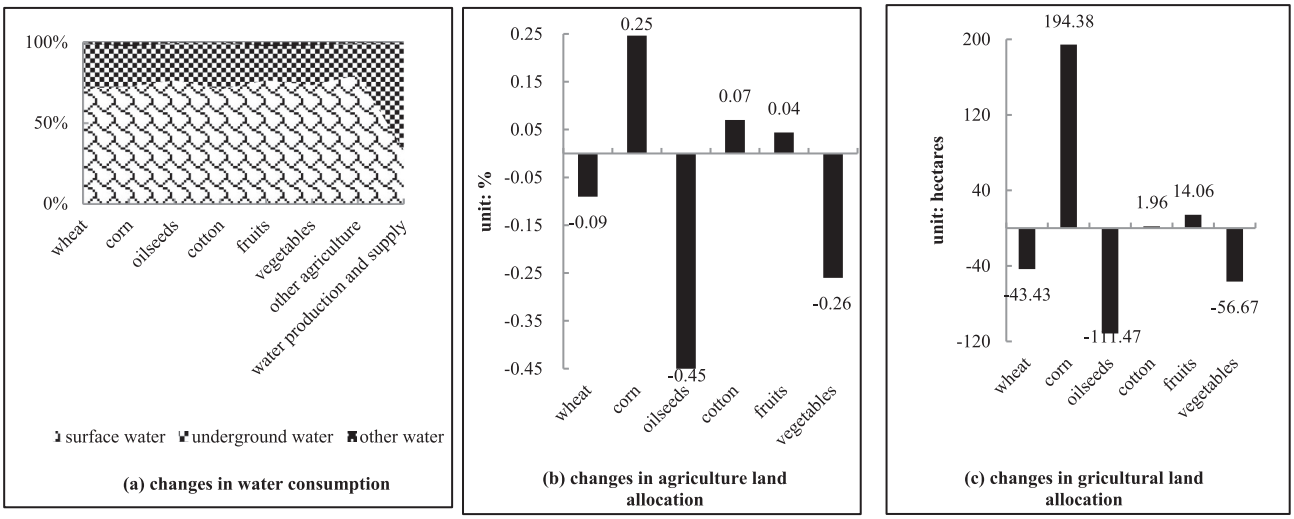

Fig. 5. Changes in water consumption and agricultural land allocation across sectors –resulting from an increase in the surface runoff caused by climate change.

that of economic crops (e.g. oilseed, cotton, fruit and vegetables). This is because in the basic database, the water intensity of grain crops themselves is higher than that of economic crops. Among them, the water consumption of corn increases most (8876.89 million m^3), followed by fruit (3394.01 million m^3), wheat (2917.06 million m^3), vegetables (2375.77 million m^3), other agriculture (880.03 million m^3), oilseed (493.33 million m^3), cotton (197.21 million m^3) and water production and supply (78.25 million m^3), a total of 19212.55 million m^3, accounting for 99.99% of total increased water consumption.

To be more specific, the reason why the water consumption of corn increases most is that the water intensity of corn is relatively high, ranking second in all agricultural products. With falling surface water price, surface water consumption for corn increases. And the output expansion of corn also drives the consumption of underground water and other water to increase. Similar phenomena are observed in the water production and supply sector and other agricultural sectors like fruit, wheat and vegetables. Contrarily, the water intensity of cotton is highest, but its water consumption ranks four. This is mainly because in the basic database, the economic scale of cotton is small. That is to say, its response to water price change is relatively insensitive. For oilseed and other agriculture, the increase in water consumption is the result of price substitution effect. Relative to other primary factors, the lower water price will lead to an increase in demand for water consumption. Considering the three types of water consumption, the increase in surface water consumption is due to an increase in surface runoff caused by climate change lowering surface water prices, resulting in an increased demand for surface water. The other two kinds of water also increase because of economy scale expansion effect greater than water price substitution effects. Although the prices of underground water and other water become relatively expensive compared to surface water, the output expansion of sectors such as corn, wheat, fruit, and vegetables lead to an increase in demand for these two kinds of water consumption.

Fig. 5(b) shows the changes in agricultural land allocation across sectors due to an increase in surface runoff caused by climate change. In the model setting, non-agricultural land and agricultural land cannot transfer, and non-agricultural land cannot be transferred across sectors. Therefore, only agricultural land demand has changed. The simulation results show that the land demand for corn increases most (0.25%), followed by cotton (0.07%) and fruit (0.04%), where the output scale effect contributes most, indicating that the output expansion of these three sectors stimulate land demand. On the contrary, the land demand of oilseed decreases most (−0.45%), followed by vegetables (−0.26%) and wheat (−0.09%), where the prices substitution effect of primary factor contributes most. That is to say, compared to the water price, the relatively higher prices of land cause lower consumption than other primary factors. From the quantity of land transfer, the land is mostly transferred from economic crops (−152.13 ha) to grain crops (150.95 ha) (total based on Fig. 5(c)).

4. Discussion

This paper, based on the climate model (GCMs) and economic model (CGE model), first used the climate model to get the annual average cumulated runoff from year 2001 to 2030 and found that climate change would cause the precipitation to increase by 8.84% in 2016–2030 compared with 2001–2015 in Zhangye City. Many studies showed that future precipitation changed with regional differences, meaning increased precipitation in some regions, while reduced precipitation in other regions (IPCC, 2013; Xue et al., 2017; Piao et al., 2010). Zhang et al. (2016) calculated the runoff of the Heihe river basin would increase by 11.4% and 12.8% respectively under scenario RCP4.5 and RCP8.5 in the period 2021–2050 compared to 1981–2010, and the results of Wu et al. (2015) showed that the runoff of the Heihe river basin would increase by 9.8% in 2006–2030 compared to 1981–2005. Therefore, our result was consistent with these references, which indicated our results had a certain credibility (Wu et al., 2015; Zhang et al., 2016). Increased surface runoff in future would stimulate the water use by direct user, like the agricultural sector. This might not only bring about economic growth, but also cause some issues to be noticed. First, increased output in the agricultural sector was not conducive to the adjustment of industrial structure in Zhangye City. Second, output expansion in the agricultural sector would increase the use of groundwater and other water. Many studies have shown that the reduction of groundwater in the area has caused serious ecological damage (Wang et al., 2014; Xi et al., 2010; Ding and Zhang, 2002). So, this may have a negative impact on groundwater and ecological environment protection, which needs to attract the attention of government.

With regard to the economic impact of surface water, there existed some studies on the impact of water supply change on economy of meta cities, such as Tianjin and Beijing in China (Deng et al., 2008; Liu et al., 2012). On the one hand, these studies either focused on climate model (e.g. GCM), or economical model based on subjective assumption. Liu et al. (2012) showed that the different changes of water supply had different impact on economy. Different with these subjective assumptions, this study has achieved the coupling mechanism between climate model and economical model in Zhangye City. The surface runoff in our

study was calculated by the climate model GCMs and SWAT, which was closer to the actual situations. Then the increased value of surface runoff in 2016–2030 was introduced to CGE model to analyze the economic impact of surface runoff, providing a new perspective to the related research field. On the other hand, the industrial structure of the meta cities was completely different from Zhangye City, in which agriculture played an important role. The results of Liu et al. (2012) and Deng et al. (2008) showed that the GDP of Beijing and Tianjin increased by 0.084% and 0.033%, respectively, for every 1% increase in water supply (Deng et al., 2008; Liu et al., 2012). Compared with this, the GDP of Zhangye city increased more than their by 1.358%. This was mainly because agriculture accounted for a larger share of GDP in Zhangye, and was more affected by the supply of surface water. According to the economic structure and water characteristics of Zhangye City, an improvement about CGE model was introduced in respect of land accounts and land-water nesting. water was divided into surface water, underground water and other water so that the impact on surface water could be realized through CGE model, and the changes in the price and demand of primary factors brought about by the changes in different types of water could be analyzed at the same time. Besides, Zhangye City's surface water was mainly used in the agricultural sectors, and Zhangye City has been one of the top ten commodity grain bases and one of the twelve vegetable and fruit bases in China. In order to recognize the different water impact of various agricultural sectors, we divided agriculture sector into seven sectors, wheat, corn, oilseed, cotton, fruit, vegetables, and other agriculture. Moreover, the CGE model fixed the prices of electric power, underground water and other water, which was consistent with the real economy, and made an economic model closer to the real economy. In general, the study of Zhangye City could provide important reference for the agriculture city and the arid and semi-arid zone.

5. Conclusion and policy recommendation

Taking Zhangye City as an example, this study is based on climate model GCMs and economical model CGE incorporated water and land resources account to analyze the likely impact of an increase in surface runoff caused by climate change on the economy and reallocation of water and land. The simulation results show that climate change would cause the surface runoff in Zhangye City to rise by 8.84% during 2016 and 2030. Further, the increase surface runoff makes Zhangye City's GDP appear to rise slightly by 0.12%. When it comes to sector output performance, there are varying degrees of output expansion or contraction in different sectors. Most benefited sectors are the agricultural sectors, water production and supply sector, mainly because the increase in surface water drives down the surface water price, leading to a cost advantage. Damaged sectors are found to be mostly export-oriented sectors, mainly due to the export demand fall through the upstream and downstream production chains.

With economic growth, total water consumption increases by 8.11%, with the surface water, underground water and other water rising by 8.84%, 6.69% and 5.73%, respectively. The consumption of surface water increase is due to the falling price as the surface water supply increasing caused by climate change. The consumption of underground water and other water also increase because economy scale expansion effect is greater than water price substitution effect, that means the increased demand for these two kinds of water caused by the output expansion of agricultural sector (e.g. corn, wheat, fruit, and vegetables) is greater than the decreased demand caused by a rise of their prices relative to surface water. In terms of sector, the increase of water consumption in corn, fruit, wheat, vegetables, other agriculture, oilseed, cotton and water production and supply, totals 19212.55 million m^3, accounting for 99.99% of total increased water consumption. For crop varieties, the increase in water consumption of grain crops (e.g. wheat and corn) is greater than that of economic crops (e.g. oilseed, cotton, fruit and vegetables). This is because the water intensity of grain crops is higher than that of economic crops. Besides this, increased surface runoff caused by climate change can cause land to transfer from economic crops to grain crops. In the agricultural sector, land demand for corn increases most and land demand for oilseed decreases most.

Based on the results of this study and in view of the geomorphic features and economic structure of Zhangye City, even if climate change increases surface runoff in the future according to climate model, the government should pay attention to changes in the consumption propensity of other types of water resources, such as underground water and other water, and continue to promote agricultural water-saving measures and promote the adjustment of agricultural planting structure, for example, adjust the planting structure to drought-resistant and high-yield crops. Besides, the increase of water consumption used by grain crops (e.g. wheat and corn) is greater than that of economic crops (e.g. oilseed, cotton, fruit and vegetables), and the land is mostly transferred from economic crops to grain crops. In recent years, economic crops like oilseeds, vegetables, and Chinese herbal medicines have developed rapidly in Zhangye City. The three major crops accounted for 83.7% of the total area of the economic crops. According to the small water intensity of economic crops, and the flow of land from economic crops to grain crops, the government should pay attention to the impact of the changes in water prices caused by climate change on these economic crops. From the perspective of sectors, the agricultural sectors benefit most, while some industrial products are hampered due to the output contraction, this is a warning sign for the government to advance the pace of industrialization. For employment, the increased labor demands of the agricultural sectors are in the majority. This is unfavorable to Zhangye City's economic development, as agricultural value-added product is low but this is related to the situation that agriculture is the major output in Zhangye City. Therefore, it is necessary for the government to improve the value added of agricultural products and develop secondary industry to optimize the industrial structure.

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